

# Design an Adaptive Neuro Fuzzy Inference System to Enhance the Performance of Perdawd CCGS in Kurdistan of Iraq

Dr. Eng. Wassan Adnan. Hashim

**Abstract**—This paper describes a design procedure for an ANFIS based power system stabilizer (ANFIS-PSS) and investigates their robustness for a single machine infinite bus system. Speed deviation of a machine and output power active is chosen as the input signals to the ANFIS-PSS. A Perdawd CCGS that connected to Kurdistan Regional Power System of Iraq (KRPS) is used as the case study. Computer simulations for the test system subjected to transient disturbances i.e. a three phase fault, were carried out and the results showed that the proposed controller is able to prove its effectiveness and improve the system damping when compared to a conventional lead-lag based power system stabilizer controller. Finally, several fault and load disturbance simulation results are presented to stress the effectiveness of the proposed ANFIS-PSS in a station studied and show that the proposed intelligent controls improve the dynamic performance of the ANFIS-PSS and the associated power network.

**Index Terms**— ANFIS, CCGS, KRPS, Grid-Partition, Power System Stabilizer.

## 1 INTRODUCTION

The concept of intelligent control was first introduced nearly two decades ago by Fu and G. Saridis [1]. Despite its significance and applicability to various processes, the control community has not paid substantial attention to such an approach. In recent years, intelligent control has emerged as one of the most active and fruitful areas of research and development within the spectrum of engineering disciplines with a variety of industrial applications.

In general, a large number of artificial control systems and advanced technologies have been applied for processing non-linear systems problems, in significantly and effectively, such as fuzzy logic systems, neural networks and hybrid intelligent systems.

However, the hybrid intelligent systems is considered as a one of the effective of artificial control systems that combined the main features of artificial neural networks with those of fuzzy logic systems, since this margining process has been shown a new technologies are: neuro-fuzzy systems, the neural network-driven fuzzy reasoning systems and the hybrid neural network-based systems. It gets the advantage of neural networks as well as of fuzzy logic system and it removes the individual disadvantages by combining them on the common features. The algorithm steps of different layers and details of ANFIS have been explained in [2].

Due to the fast development of intelligent techniques applications in power systems during this decade, many research-

ers in the field of power systems have paid more attention to applications of such techniques to solve power system problems. The PSSs are designed through different intelligent techniques such as Particle Swarm Optimization, Ant colony Optimization, Genetic Algorithms, Artificial Neural Network (ANN), Fuzzy logic, Neuro-Fuzzy have been proposed by [3-7].

The Main Objectives of this work are summarized as follows:

- To present a definition of neuro-fuzzy systems and detailed explanation of the structure of adaptive neuro-fuzzy inference system.
- Adoption a real mathematical model of Power System Stabilizer(PSS) for electrical power generation station of the Perdawd CCGS Connected to the Kurdistan Regional Power System of Iraq
- To employ the parameters of operating conditions and exciter as an input to ANFIS and the parameters of PSS as an output to ANFIS.
- To investigate and compare the effectiveness and robustness of the Adaptive stabilizer with the conventionally tuned PSS at different operating conditions and large perturbation by using Matlab®/Simulink®.

## 2 FORMATING INSTRUCTION NEURO-FUZZY SYSTEMS

The integration of fuzzy logic systems with neural networks reduces the limitations of fuzzy systems in terms of lack of learning while strengthening the neural network features in terms of explicit knowledge representation. According to this integration, neuro-fuzzy technique is described as hybrid systems.

• Wassan Adnan Hashim is Ph.D in Automatic control & Automation Engineering, Computer Science, Bayan University, Erbil, Iraq, E-mail: wassanhashim@gmail.com

Neuro-fuzzy systems (NFS) can be divided into three major types [1], [8]:

- Cooperative Neuro-Fuzzy Systems
- Neural Network-Driven Fuzzy Reasoning Systems
- Hybrid Neuro-Fuzzy Systems

Figure 1 depicts the mapping from a fuzzy logic system to a neural network structure

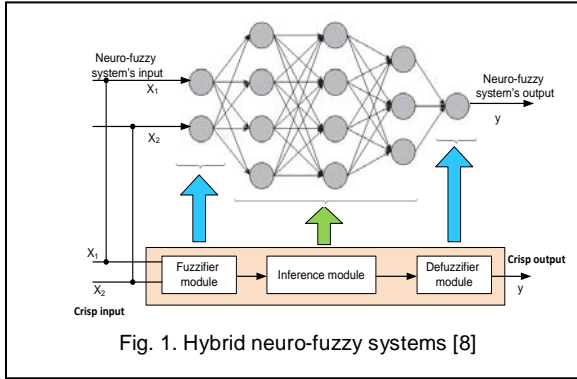


Fig. 1. Hybrid neuro-fuzzy systems [8]

### 3 ADAPTIVE NEURO FUZZY INFERENCE SYSTEM

The ANFIS refers, in general, to an adaptive network that performs the function of a fuzzy inference system. ANFIS was first proposed by Wang in 1992 [9]. The most commonly used fuzzy system in ANFIS architectures is the Sugeno model, since it is less computationally exhaustive and more transparent than other models. A consequent membership function (MF) of the Sugeno model could be any arbitrary parameterized function of the crisp inputs, most likely a polynomial.

The adaptive network employs an optimization algorithm in order to modify the parameters of the fuzzy inference system. The adaptation process aims at obtaining a set of parameters at which an error measure between the actual performance of the fuzzy inference system and a targeted set of training data is minimized. Classical optimization techniques, such as back propagation, could be used as well as hybrid algorithms. The total number of ANFIS-modifiable parameters is a crucial factor of the computational effort required before the adaptation process is completed. Therefore, the antecedent Gaussian MF, which is defined through two parameters only, is more preferable than other forms of MFs, which require three or more parameters [10, 11].

The ANFIS combines the advantages of fuzzy systems and adaptive networks in one hybrid intelligent paradigm. The flexibility and subjectivity of fuzzy inference systems, when added to the optimization strength of adaptive networks, give the ANFIS its remarkable power of modeling, learning, non-linear mapping, and pattern recognition [12, 13].

The structure of ANFIS consists of a five-layer feedforward network. The nodes in each layer have the same functionality. ANFIS only supports Sugeno-type systems, with the following constraints:

- First or zero order Sugeno-type systems.
- Single output, obtained using a weighted average de-

fuzzification method (linear or constant output membership functions).

- The weight of each rule is unity.

So, to present the ANFIS architecture, let's consider two fuzzy if-then rules based on a first order fuzzy Sugeno model [8, 14, 15].

$$R_p = \text{if } x_1 \text{ is } A_i \text{ and } x_2 \text{ is } A_2^p \text{ and } x_n \text{ is } A_n^p$$

$$\text{then } O_p = \alpha_0^p + \alpha_1^p x_1 + \dots + \alpha_n^p x_n \dots (1)$$

Where  $x_i$  is  $i$ -th input linguistic variable in the antecedent part of the  $p$ -th rule with  $i = 1, \dots, n$  and  $(A_i^p)$  is the linguistic label associated with it in that rule.

$(A_i^p)$  has its associated fuzzy membership function given by

$$\cdot (\mu_{A_i^p}(x_i))$$

$(O_p)$  is the consequent output of the  $p$ -th rule and  $(\alpha_0^p, \dots, \alpha_n^p)$  are the Sugeno parameters. Figures 2 and 3 illustrate the ANFIS five-layer architecture for a two-input ( $i = 1, 2$ ) one-output first order Sugeno fuzzy model with four rules ( $p = 4$ ).

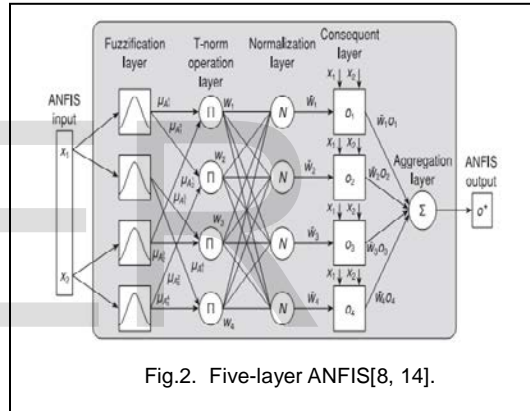


Fig.2. Five-layer ANFIS[8, 14].

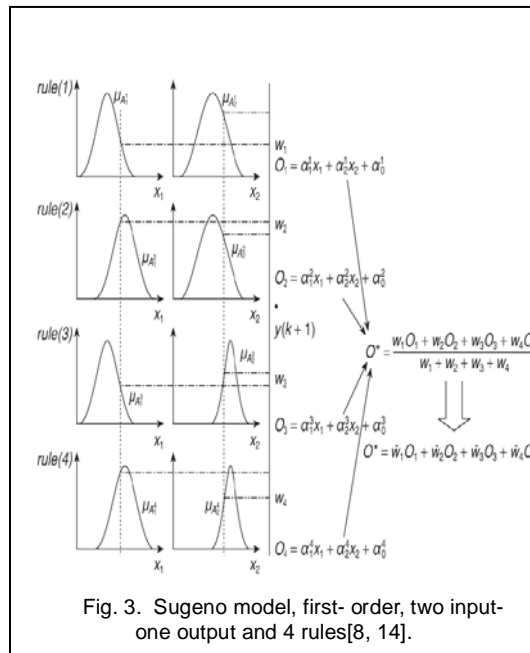


Fig. 3. Sugeno model, first-order, two input-one output and 4 rules[8, 14].

### 3.1 Adaptive Neuro Fuzzy Inference System-Grid Partition

Grid partition divides the data space into rectangular sub-spaces using axis-parallel partition based on pre-defined number of membership functions and their types in each dimension, as shown in figure 4. Premise fuzzy sets and parameters are calculated using the least square estimate method based on the partition and MF types. And, it's also used to determine the consequent in the output member function (MF), resulting in a valid fuzzy inference system (FIS). When constructing the fuzzy rules, consequent parameters in the linear output MF are set as zeros. Hence it is required to identify and refine parameters using ANFIS [11].

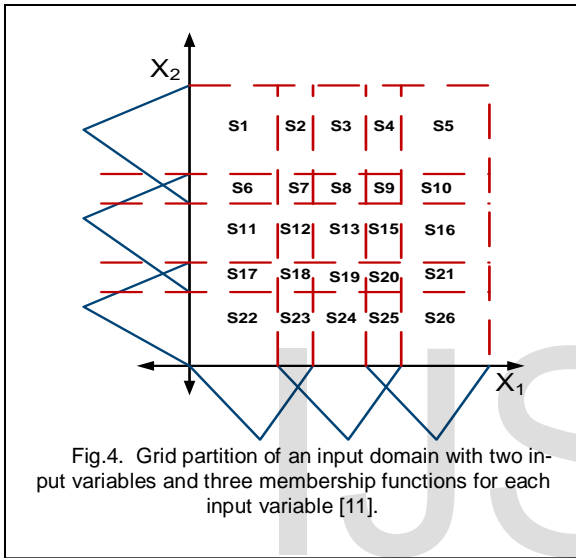


Fig.4. Grid partition of an input domain with two input variables and three membership functions for each input variable [11].

While the grid-partitioning approach has the advantage that all fuzzy rules can be generated using a relatively small number of linguistic variables, it suffers nevertheless from serious disadvantages. The size of fuzzy rules generated by the grid-partitioning techniques grows exponentially. This problem is known as the curse of dimensionality.

## 4 APPLY ANFIS FOR ENHANCEMENT THE DYNAMIC STABILITY OF ELECTRICAL POWER SYSTEM (PERDAWD COMBINED CYCLE GAS STATION (CCGS))

Kurdistan Regional Power System of Iraq (KRPS) comprises two hydro power stations, Dokan (400 MVA) and Darbandikhan (249 MVA) in addition to two gas stations cited at Perdawood (500 MVA) and Chamchamal (750 MVA). Another two more gas stations are under construction in Duhok (200 MVA) and TaqTaq(200 MVA). The four gas stations are private sector investments. Currently, KRPS uses 35 load nodes at 132 kV substation ends totaling 2202 MW. The system serves five million population in an area of 80,000 square km[16].

### 4.1 System Modeling

Perdawd CCGS is considered here as a practical case study. It includes the following components: the nonlinear machine model with a 2-axis representation of the generator, the excitation system type IEEE ST1A, and conventional lead/lag power system stabilizer (CPSS) as shown in figure 5 [17].

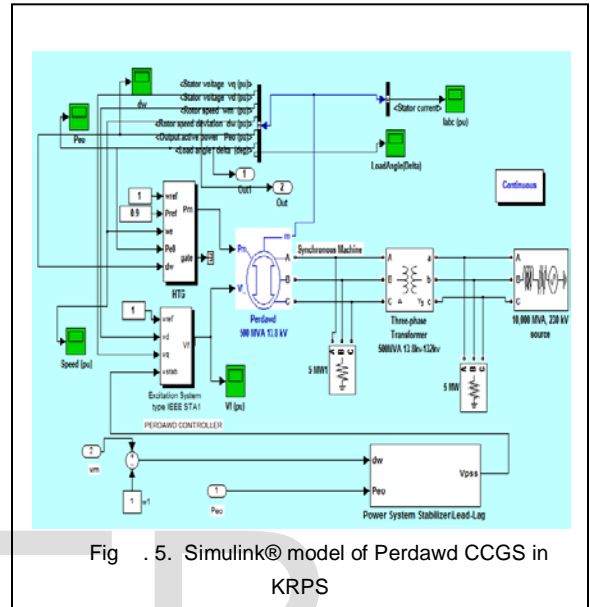


Fig . 5. Simulink® model of Perdawd CCGS in KRPS

To enhance the dynamic stability and avoid the fault disturbance that was faced Perdawd CCGS in control unit (power system stabilizer), ANFIS is introduced to improve the dynamic response of station studied by designing the parameters of perdawd controller and CPSS.

### 4.2 Modeling of ANIFS, Training And Testing

The core of the proposed ANFIS is designed from fuzzy linear model type Sugeno, convert a fuzzy inference engine into an adaptive network that learns the relationship between inputs, defined by the operating conditions and parameters of excitation system (Tlead, Tlag, K=f(k1, k2), Ti, KF, TF), and outputs, defined by the PSS parameters (Kpss,Tw,Tw1,TLead1,2,3,TLag1,2,3 ). These relationships are learned independently for each PSS parameter, therefore nine ANFIS are used for each PSS controller, in order to improve the converge speed of the ANFIS hybrid learning algorithm. 1500 input-output data pairs were obtained for the training of the ANFIS for each PSS controller. The available data set is randomly partitioned into a training set and a checking set. The training set provides desired input/output pairs used during the training stage, while the checking set is used for testing the generalization capability of the ANFIS through a cross-validation. For initializing of FIS rules, the grid partition method has been used and the initial rules are extracted. Figure 6 shows the flowchart of ANFIS for station studied.

ing process of ANFISGRID network was consumed (43200 sec) of CPU time for each parameter of PSS

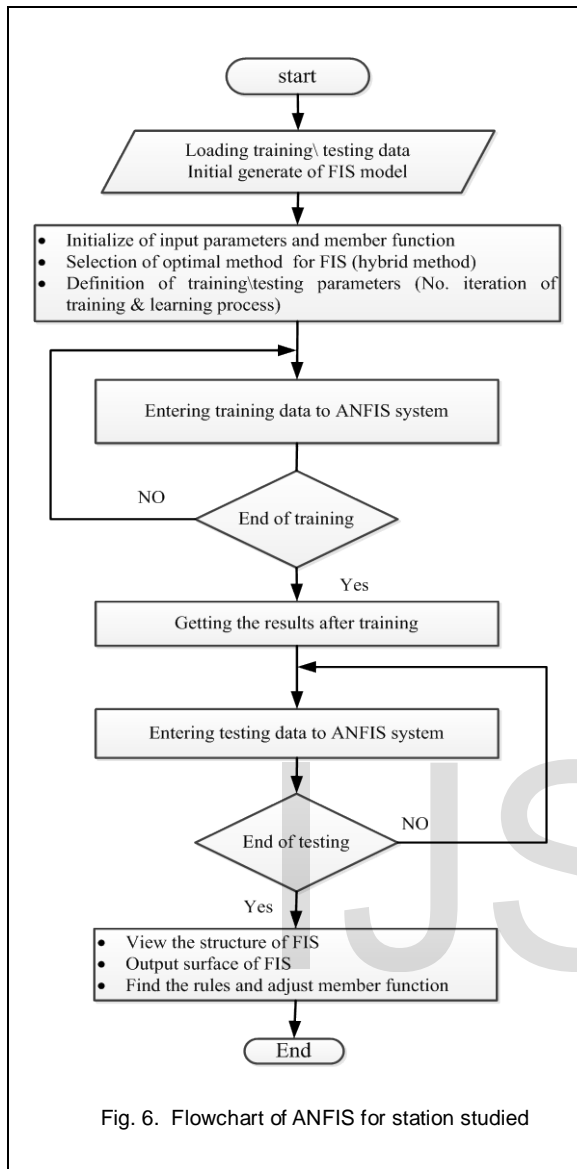


Fig. 6. Flowchart of ANFIS for station studied

### 4.3 Apply Adaptive Neuro-Fuzzy Inference System-Grid Partitioning-ANFISGRID

Since, choosing the correct number of membership functions is a fundamental question often raised in these applications. Usually this number is determined experimentally in a similar way to choosing the number of neurons in the hidden layer of an artificial neural network. But there are other methods based on pruning or growing the network. Pruning algorithms start with a larger network and then prune it to desired size. On the opposite, growing algorithms start with a small network and gradually increase it to appropriate size [13]. In this study, three membership functions (MFs) are assigned to each linguistic variable, according that, the desired network has 751 fuzzy rules as shown in figure 7. Then, training algorithm is implemented on the PSS parameters of station studied. Train-

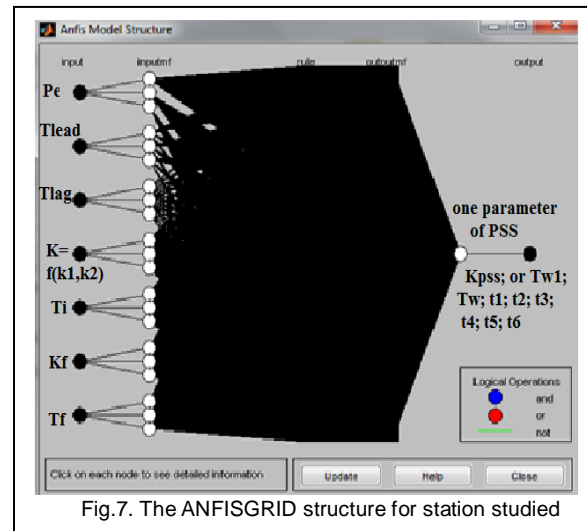


Fig.7. The ANFISGRID structure for station studied

Figures (8a) and (8b) show the uniform falling of the value of testing error to minimum value with the number of iterations (600 cycle) during the testing process for the training set and the checking set of adaptive PSS parameter, Kpss. In figure (8c), the ANFIS output is validated using the checking data.

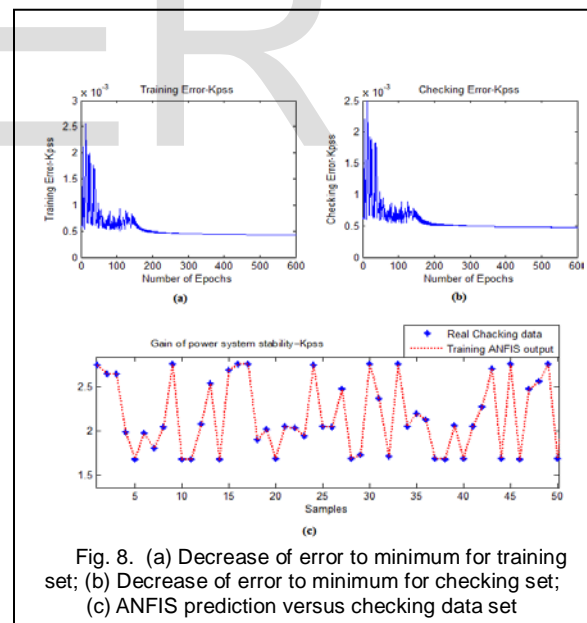


Fig. 8. (a) Decrease of error to minimum for training set; (b) Decrease of error to minimum for checking set; (c) ANFIS prediction versus checking data set

## 5 SIMULATION ANALYSIS AND DISCUSSION

To demonstrate the effectiveness of the ANFIS to enhance power system stabilizer performance of station studied, time domain simulations with ANFIS-PSS were performed for Perdawd CCGS under three-phase fault (5-cycle of simulation time) at nominal loading conditions. MATLAB\Simulink has been used for the analysis. Figure 9 illustrates the dynamic

response of station studied with CPSS, and with adaptive PSS (ANFIS-PSS)

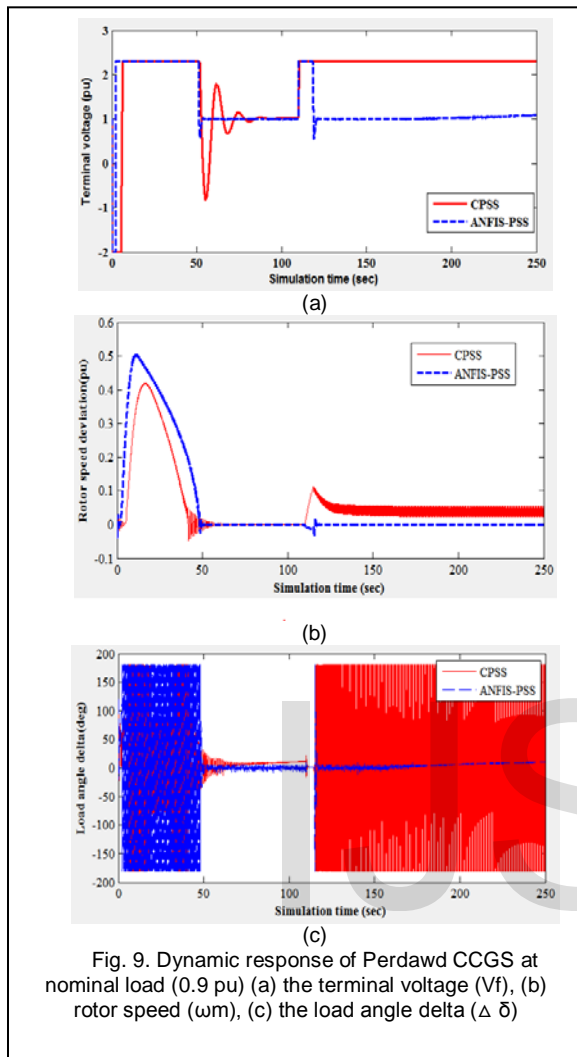


Fig. 9. Dynamic response of Perdawd CCGS at nominal load (0.9 pu) (a) the terminal voltage (Vf), (b) rotor speed ( $\omega_m$ ), (c) the load angle delta ( $\Delta \delta$ )

From above analysis, we notice that the response of station studied with CPSS is unstable at external voltage ( $V_f = 1$  pu) during disturbance and could be caused melting. So, an adaptive PSS is employed for station studied that it is tuned parameters by ANFIS-GRID network.

Note here that, the dynamic stability of station studied enhances by using adaptive power system ANFIS-PSS where the system is stable at external voltage ( $V_f = 1$  pu) with highly oscillatory. Also, the critical clearing time (CCT) of system at CPSS is very highly compared with other situation (ANFIS-PSS) that is equal (35 sec).

## 6 CONCLUSION

In this study, ANFIS-PSS is proposed for damping oscillations and the effectiveness of the proposed control system is compared with Conventional controller under some disturbances. The controller is tested on a real case study, Perdawd CCGS power station in KRPS of Iraq. From the results it can be concluded that the ANFIS-PSS produces no steady state error and

acceptable overshoot under some disturbances.

The work in this research involves a design of ANFIS-PSS, which is built based on the data generated by the conventional controller. The generation of fuzzy rule-based and input-output domain ranges has been investigated. It has been found that the ANFIS-PSS provides more robust control against several disturbances with quicker settling-times when compared with a conventional lead-lag stabilizer.

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